An Investigation of Response Bias in Tone Glide Direction Identification

A Senior Honors Thesis

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by

Matthew J. Gould

The Ohio State University
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Project Advisor: Professor Lawrence L. Feth,
Department of Speech and Hearing Science

Dedication

I would like to dedicate my undergraduate honors thesis to Dad and Mom for all the sacrifices you've made for me. It is through your guidance and support that I realized my dream of attending The Ohio State University. Thank you for always pushing me to be the best that I can be.

"Success – It's what you do

with what you've got."

--Woody Hayes

Abstract

Encoding speech is effortless for the average human listener. Speech sounds are identified by different patterns of resonance in the vocal tract called formants. The transitions between formants are essential to the understanding of speech. More specifically, the direction of frequency change ("up" or "down") across formant transitions is of particular interest. In this experiment, frequency-modulated (FM) tone glides were used to approximate basic characteristics of formant transitions in speech. The study is a partial replication of two previous studies that reported a difference in accuracy when identifying "up" vs. "down" tone glides. In order to determine whether these differences were attributable to response bias, this study used a two-interval forced choice procedure. Four young adults with normal hearing performed the task by listening to two intervals, one containing a rising or falling tone glide and the other a tone with constant frequency. They were asked to respond by choosing the interval which contained the tone glide. Three center frequencies were tested: 850, 2250 and 3850 Hz. All four subjects were able to identify glides rising in frequency with better accuracy than glides falling in frequency across all three center frequencies. The largest gap in accuracy of detecting "up" vs. "down" glides was at 2250 Hz. Statistical analysis of subject responses confirmed that three out of four subjects did not exhibit a response bias. Therefore, there must be an alternative explanation for the difference in direction identification for "up" vs. "down" tone glides.

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Chapter One - Introduction

Listening to speech is a rather effortless task for the average human listener. Children learn the elements of communication at a very young age, and speakers typically put little thought into how the process actually works. When a speaker talks, their message must be encoded in a stream of sound energy to be understood by the listener. Air is forced from the lungs, proceeds through an opening in the larynx, called the glottis, and exits through either the oral or nasal cavity. The glottis is shaped by two tiny muscles called the vocal folds (or vocal chords). Subglottal pressure forces the vocal folds to open. When the pressure in the glottis drops, the pressure changes and elasticity of the vocal folds cause them to come back together and repeat the cycle. This phenomenon is known as the Bernoulli Effect (in which pressure times velocity is always constant). Voicing is the result of this effect, the vocal folds alternately snapping apart and back together. The rate of this vibration determines a speaker's fundamental frequency. In speech articulation, a consonant is very short in duration and is characterized by an obstruction in the vocal tract. However, a vowel is produced with no pressure build-up or obstruction and much longer in duration. Consonants can either be voiced or voiceless; however, all vowels are voiced.

While air is being exhaled and glottal activity is creating voicing, articulators such as the tongue, teeth, lips and velum are constantly moving to shape different sounds. This is known as the source-filter model of speech production, in which speech sounds are comprised of a source component originating at the vocal folds and a filter component that changes with the shape of the vocal tract. Consonant articulation can differ in both place (location of obstruction) and manner (type of obstruction). Examples of place of articulation include: bilabial (using both lips; /p/, /b/, /m/), alveolar (tongue closure with alveolar ridge behind teeth; /t/, /d/, /n/, /s/, /z/), velar (back of tongue makes closure with velum; /g/, /k/, /ŋ/) among others. Consonants can share the same place of articulation and differ in manner of articulation. For example, a stop consonant (/p/, /b/, /t/, /d/, /k/, /g/) is formed by creating an obstruction in the airflow followed by a release. Although /p/ and /t/ differ in place of articulation, they are both stop consonants. The most common types of manner include: stops, nasals (created by lowering the velum; /m/, /n/, /ŋ/) and fricatives (air flowing through a narrow channel; /f/, /v/, /s/, /z/, /ʃ/, /□/, /θ/, /ð/). Vowels are always voiced and differ in tongue height (high or low), location (forward or back) and lip roundedness. For a full description of English consonants and vowels, refer to Figure 1.1 and Table 1.1.

Vowel Chart

Hi →	ɩ (beat)		u (boot)
	I (bit)		ʊ (book)
	e^{i} (bait)		o^{ʊ} (boat)
Mid →			
	ɛ (bet)		ɔ (ughtbo)
		(unstressed) ə (*a*live)	
	æ (bat)	(stressed) ʌ (but)	a (bottle)
Low →			
	↑ **Front**	↑ **Center**	↑ **Back**

<u>Diphthongs</u>
aɪ (bite)
ɔ ɪ (boy)
aʊ (cow)

Figure 1.1 – A chart of English vowels, by tongue location and height. An example is given next to each vowel of an English word containing the vowel. Diphthongs are a combination of two vowels.

Consonant	Voiced/Voiceless	Place of Artic.	Manner
m	+v	Bilabial	Nasal
p	-v	Bilabial	Stop
b	+v	Bilabial	Stop
f	-v	Labiodental	Fricative
v	+v	Labiodental	Fricative
θ	-v	Interdental	Fricative
∂	+v	Interdental	Fricative
t	-v	Alveolar	Stop
d	+v	Alveolar	Stop
n	+v	Alveolar	Nasal
s	-v	Alveolar	Fricative
z	+v	Alveolar	Fricative
r	+v	Alveolar	Lqd (Retroflex)
l	+v	Alveolar	Lqd (Lateral)
ʃ	-v	Palato-Alveolar	Fricative
ʒ	+v	Palato-Alveolar	Fricative
tʃ	-v	Palato-Alveolar	Affricate
dʒ	+v	Palato-Alveolar	Affricate
j	+v	Palatal	Approximate
k	-v	Velar	Stop
g	+v	Velar	Stop
ŋ	+v	Velar	Nasal
w	+v	Labiovelar	Approximate
h	-v	Glottal	Fricative

Table 1.1 – Consonants of the English language are listed in this table in terms of their voicing, place and manner of articulation (+v refers to the presence of voicing).

The smallest units of sound in a language are referred to as phonemes. One phoneme can differ from another by just one feature: voicing, place or manner of articulation. Therefore, each phoneme is produced using a combination of the place and manner of articulation, and the presence or absence of voicing (vibrations of the vocal cords). For example, /p/ and /b/ have the same place (bilabial) and manner (stop) of articulation, but differ only in voicing. However, /s/ and /ʃ/ (“sh-”) are both voiceless fricatives, but differ in place of articulation; the tongue placement for /s/ is alveolar while /ʃ/ is post-alveolar, occurring behind the alveolar ridge. The discrimination of two phonemes relies on the ability of an individual to perceive these small acoustical differences between separate phonemes. Phonemes are grouped together in clusters to produce syllables, word phrases and sentences.

Each combination of voicing (present or absent), place of articulation (bilabial, alveolar, velar, etc.), and manner of articulation (stop, fricative, nasal, etc.) results in a separate consonant. By moving the articulators, a speaker shapes the mouth in many different ways, causing the volume of the oral cavity to change. This change in volume creates acoustical differences and the way speech is perceived. For example, when articulating for the vowel /u/ the tongue is high and back in the mouth, and the lips are rounded. In this case, the volume of the oral cavity is decreased. In contrast, a doctor may ask a child to articulate the vowel /a/ when examining the oral cavity, because the tongue is low and forward in the mouth and the volume increases. As the volume changes, so do the resonant frequencies. The key to detecting /a/ vs. /u/ lies in the form and direction of the formant frequencies.

When communicating face-to-face, one has the advantage of visual cues. However, when a listener is not given the benefit of having visual cues, the key to understanding speech for the listener is to detect various acoustic cues. The perception of speech is carried out through a series of stages in which acoustic cues are extracted. A change in shape of the vocal tract acts as an important cue for a listener to perceive a /d/ instead of a /g/, due to differences in formant frequencies. Typical examples of acoustic cues are the length of the release burst (voice onset time) of stop consonants including /p/,

/b/, /t/, /d/, /k/ and /g/, and the frequency of the second formant at voicing onset. The only difference between /ba/ and /pa/ is that the voice onset time for /ba/ is shorter than the voice onset time for /pa/. Just as it is important for a speaker to encode a message, in order to understand the message, the listener must be able to de-code the information.

Both the shape of the vocal tract and the length of the vocal cords directly impact the types of sounds produced during speech. A person with longer vocal chords naturally produces speech at a lower fundamental frequency than a person with shorter vocal chords. In addition, when the vocal folds are stretched, tension results in higher frequency vibration. Similar to strings on a guitar, shorter vocal folds or more tension creates a higher rate of vibration and a higher resulting pitch. The shape of the vocal tract and articulation of different consonants results in a filtering of the fundamental frequency created at the vocal folds. The resonating frequencies caused by the filter are called formant frequencies. The formant frequencies are determined by the shape and length of the vocal tract. Therefore, by moving the articulators such as the velum and tongue the shape and length of the vocal tract changes and results in a shifting of the formant frequencies (see Figure 1.2 for a further depiction of the filter process of different vowels).

During the closure for a stop consonant, no sound is emitted due to the vocal tract being completely closed off. At the moment of release, the resonances change rapidly. The shape of the vocal tract, which varies for each stop consonant, affects the resonant frequencies. These changes in frequency are called formant transitions. The first formant (F1) typically increases. However, the second (F2) and third (F3) can increase or decrease, depending on the place of articulation. The capability for humans to distinguish between different CV (consonant-vowel) phoneme clusters strongly depends on their ability to perceive the direction of the second and third formant transitions. The difference in a human perceiving [bi] versus [bu] lies within the form and direction of the second formant transition.

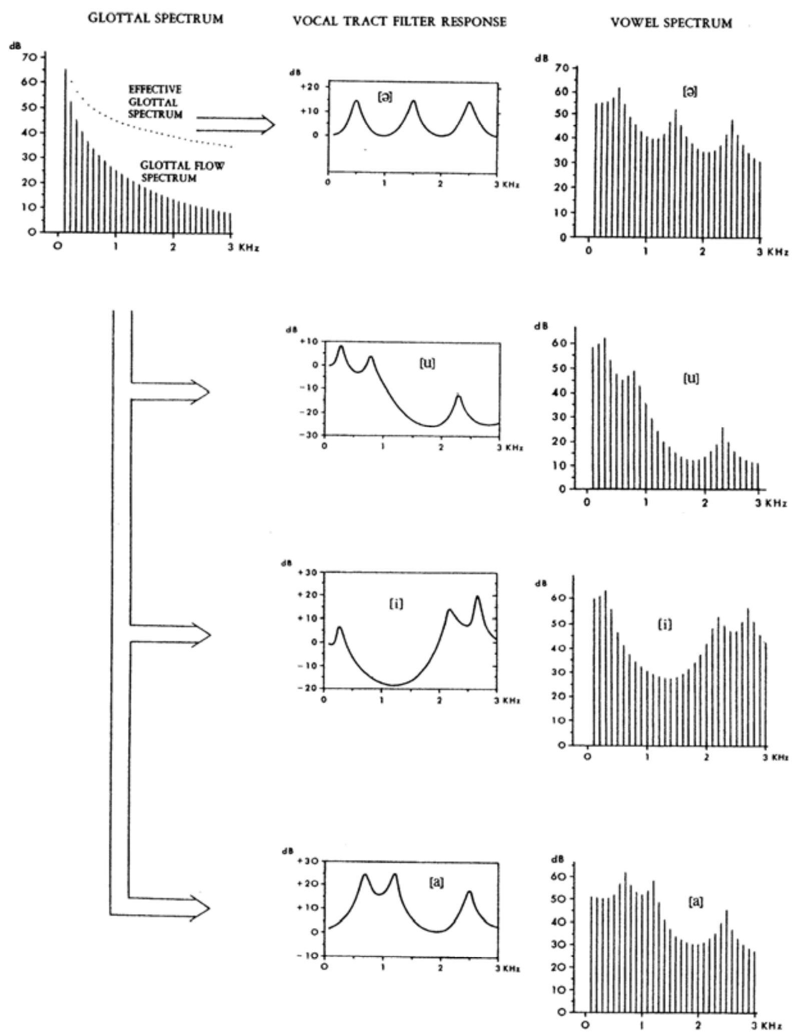

Figure 1.2 – Production of model vowels according to source-filter theory. The spectrum of the glottal sound source is modified according to filter curves resulting from the shape of the vocal tract to form the different vowel sound spectra. (Pickett, 1999)

In view of the fact that small changes in formant transitions are responsible for distinction between two different sounds, the success of speech discrimination depends on the ability of a listener to detect acoustic cues such as the direction of the second formant frequency. Experimental research has focused on the ability of humans to distinguish between acoustic cues without using speech, but by using simple sounds that have some essential characteristics of the acoustic cues of speech. In an experimental setting, tone glides are used to approximate the acoustic characteristics of formant transitions. Differences in the ability of a listener to detect a rising or falling glide can reflect a difference in detecting one speech sound opposed to another. For example, if a subject in a study is better at identifying a glide moving up in frequency over a glide moving down in frequency, they could also be better at identifying phonemes in which the second formant is moving up. This concept has led to research on differences in performance in direction identification ("up" vs. "down") of tone glides.

Past research:

Previous studies on direction identification have demonstrated an asymmetry in listener performance in detecting a rising or falling tone glide. Experimental results have indicated that a rising glide is easier to detect than a falling glide. Gordon and Poeppel (2001) found that listeners could identify rising glides more accurately than falling glides covering the same frequency range over the same duration. Their study focused on the presence of an asymmetry between rising and falling glides using a one-interval experiment with rapid FM tones at different frequency ranges and durations. Subjects listened to frequency-modulated (FM) sweeps of random direction and chose between two labeled keys "up" and "down." The difference in the accuracy of listeners to detect a rising glide versus a falling glide was most evident when the tones were presented at mid to high frequency ranges at around 20 ms in duration.

This study was partially replicated by Dawson and Feth (2002), who investigated direction identification of both FM and virtual-frequency (VF) glides. A VF glide is produced by shifting the amplitudes of two adjacent frequencies. A listener perceives a *virtual* tone that is either increasing or decreasing in frequency. Dawson and Feth initially had difficulty producing the same results of the Gordon and Poeppel study. They assumed Gordon and Poeppel must have used naïve listeners with no practice, because they had to introduce roving of the frequency before the asymmetry was evident. Roving causes a variation in beginning and ending frequencies for each glide. For example, a glide moving upward in frequency can end in a frequency lower than a glide moving downward in frequency. This forced the subjects to listen to the full duration of a glide before determining direction. In addition, the same pattern of the results of FM tone glides was also evident when testing with VF glides. This similarity in the pattern for accuracy of direction identification of VF and FM glides is probably due to both being processed in the central auditory cortex in the same way.

Issue of response bias:

There may be an alternative explanation for the results found in earlier research in direction identification. A subject could have a bias for answering "up" or "down" or by simply preferring the first or second labeled key in an experimental setting (Personal communication, Anonymous reviewer of a manuscript written by L. L. Feth, May 2005). Since half of the tone glides were moving upward in frequency and the other half downward, the subjects should have answered "up" approximately half of the trials and likewise “down” half the trials. Therefore, the first labeled key should have been used to respond for about half of the trials and the second key for the other half. However, when the task becomes too difficult and the listener must guess, response bias may lead to the listener always answering “up,” for example.

Gescheider (1976) outlines three different psychophysical procedures of the signal detection theory. He describes the method of testing used in previous studies on direction identification as a one-interval, or *yes-no procedure*. When subjects hear a tone glide, they must decide between two possible outcomes, “up” or “down,” similar to “yes” or “no.” In this type of experiment, different criterion levels can by obtained by changing signal probability or payoff contingencies. Subjects should answer “up” and “down” each about half of the time. However, the experiment must be designed to allow the measurement of bias (such as a SIAM, see Chapter 5). In both of the previous experiments on direction identification, the study was not designed for the measure of response bias.

Another technique for obtaining a measure of sensitivity described by Gescheider is the two-interval, *forced choice procedure*. By using this method, the results are less likely to be affected by a fixed preference in the listener’s criterion for responding “up” or “down”. Two intervals are presented, one containing the signal moving either up or down in frequency and the other interval containing a tone maintaining a steady frequency over the entire duration. The listener must then choose which interval contained the tone glide moving up or down. This allows for the measuring of “up” vs. “down” bias that could have affected the results of the previous experiments. Instead of choosing which tone is “up” or “down”, the subjects respond by choosing the moving tone by forced choice.

In order to measure response bias, the new study on direction identification used a two-interval, forced choice method. Only FM glides were used in this revised testing paradigm. Instead of determining if a single glide is going up or down in frequency, a subject was presented with two tones, one changing in frequency and one maintaining a constant frequency. The subjects then chose which tone is moving, whether up or down. The experiment was two-way randomized. Half of the time the desired response occurred in the first interval; on the remaining half, it occurred in the second interval. In addition, half of the glides moved up in frequency and the other half fell in frequency.

The questions to be addressed include:

-First, do the results from this study replicate the results found from Gordon and Poeppel (2001), and Dawson and Feth (2002)? Although the previous experiments were single-interval experiments, a similar pattern in direction identification should be evident in this new two-interval experiment.

-Next, is the gap in performance for “up” vs. “down” glides larger at a specific center frequency? In other words, subjects may identify “up” glides at a much greater proportion than “down” glides at one center frequency.

-Finally, do any of the subjects exhibit a response bias? The subjects’ responses for each trial are recorded and analyzed for the possibility of response bias affecting the results.

By answering these questions, the validity of the previous two experiments can be confirmed.

Chapter Two – Literature Review

The motivation for the current study relates to two previous studies on glide direction identification. Gordon and Poeppel (2001) observed the ability of human subjects to distinguish between FM glides moving “up” or “down” in frequency by altering the frequency range and the glide duration. They used three frequency ranges: 0.6-0.9 kHz, 1-1.5 kHz, and 2-3 kHz, and ten durations: 5, 10, 20, 30, 40, 50, 80, 160, 320, and 640 ms. The participants in this experiment all had normal hearing with no history of hearing or neurological problems. Each individual was asked to respond after being presented with a FM tone either rising or falling in frequency by pressing one of two keys labeled “up” or “down.” The experiment was designed to test both the accuracy in direction identification and the reaction time.

Gordon and Poeppel found a notable difference in the subjects’ ability to identify upward and downward FM sweeps, when a short duration was used. The results showed that upward FM glides were detected with better accuracy than those falling in frequency when the durations were shorter than 160 ms. The most noticeable difference took place in the mid to high frequency ranges. When the rate of the sweep was 640 ms, subjects could identify both rising and falling glides at about 95%. When the rate was as fast as 5 ms, subjects were merely guessing between whether the tone was moving upward or downward.

However, Gordon and Poeppel reported a frequency range in which the task became more difficult for an individual to distinguish a falling glide from a rising glide. Moreover, they found this noticeable difference in performance of direction identification when the high frequency signal duration was 5-160 ms (approximately 20% variation in accuracy). When reaction time was examined, Gordon and Poeppel found no such inequality in FM direction identification between the upward and downward glides. The results of this study were consistent with those found by Collins and Cullen (1978), who concluded that thresholds for detecting upward FM sweeps were lower than those for downward sweeps.

Dawson and Feth (2002) examined listener performance in detecting the direction of FM and VF (virtual-frequency) glides (see Figure 2.1 below). VF glides are created by presenting two tones very close in frequency, but the listener will perceive only one *virtual* tone, with frequency somewhere between the two presented tones. By increasing and decreasing the intensity of the two tones, the VF tone can be made to rise or fall in pitch. Although a listener perceives a FM glide similar to a VF glide, their resulting activity on the basilar membrane is very different, since there is no real movement of sound energy from one frequency to another.

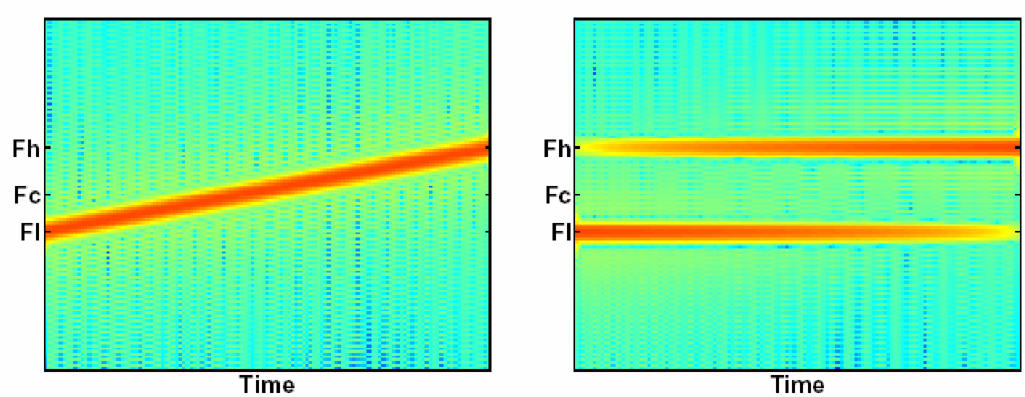

Figure 2.1 – The left picture represents the generation of an FM glide caused by changing frequency over time. Shown on the left, a VF glide is created by reversing the amplitudes of two constant frequencies over time. (Anantharaman, Krishnamurthy, and Feth, 2001)

Since Gordon and Poeppel found the clearest difference in direction identification for FM tones in the high frequency range from 5 to 160 ms, Dawson and Feth tested FM glides fitting these criteria. If their results matched those of Gordon and Poeppel, then was there a similar tendency for humans to more easily detect a rising VF glide? After initial testing, they found subjects were able to identify both rising and falling glides with 100% accuracy. For example, listeners were able to detect the direction of a falling glide by hearing only a high starting frequency. Therefore, roving of the FM glide frequency was introduced. Roving refers to the center frequency being drawn from a uniform distribution of frequencies covering one octave around the nominal center of the frequency range. This forced the listeners to give full attention to the entire duration of the glide before responding.

Eight signal durations were used during this experiment: 5, 10, 20, 30, 40, 50, 80, and 160 ms, and all signals were in the high-frequency range. The VF glides were created by modulating the amplitudes of the two end frequencies of the FM glide in which they were doing a comparison. Each block of trials contained either FM or VF signals with a constant duration, while the direction of the glide was random. Much like Gordon and Poeppel study, the listener was asked to choose between two keys, representing a glide heard moving upward or a glide heard moving downward. This principle, as Gescheider (1976) describes as a one-interval, or *yes-no procedure* was used in both experiments.

Originally, the results of this experiment for FM glides did not reflect those from Gordon and Poeppel, and the listeners became very good at the task with little practice. This led to Dawson and Feth's assumption that Gordon and Poeppel used naive listeners with no experience in psychoacoustic experiments. Roving had to be introduced to make the task more difficult in order to obtain a similar pattern in direction identification. Still, they did not find the prominent difference that was demonstrated in the previous experiment. However, there was enough evidence to conclude that listeners identify a rising glide with better accuracy than a falling glide. In addition, the direction of FM glides was easier to identify than the direction of equivalent VF glides in the same conditions. Furthermore, the psychometric functions for VF glides paralleled those for FM glides. A psychometric function is a plot of "yes" responses when the signal was present vs. "yes" responses when the signal was not present. The authors concluded that FM and VF signals are represented by similar changes in neural activity, and the difference in performance in the task was due to the FM glide being more salient.

Issue of response bias:

The results of earlier studies suggest that listeners are better at identifying glides that are moving upward in frequency. Both of these previous studies on the direction identification performance task were based on single-interval experimentation. In an anonymous review of a separate study, Dawson and Feth's results were scrutinized for the possibility of response bias playing a role in the listener's responses. It was suggested that the subjects may be biased toward answering upward rather than downward when the task becomes difficult. It is assumed, however, that an individual will answer "up" half of the time and "down" half of the time. To prevent response bias in further research, the new study on direction identification used a two-interval, forced choice method. Instead of determining if a single glide is going up or down in frequency, subjects were presented with two tones, one changing in frequency and one keeping a steady frequency. The subjects then chose which tone is changing. Half of the time the changing tone occurred in the first interval; on the remaining half, it occurred in the second interval. Likewise, half of the tones changing in frequency rose in frequency, and half fell in frequency.

Chapter Three – Methods and Procedures

Subjects:

The subjects for this experiment were four, normal-hearing undergraduate students with no history of hearing loss or neurological problems. There were three males and one female. All four were twenty-one years of age at the time of the experiment. A hearing screening was given to each listener to ensure normal hearing thresholds prior to participation in the experiment. For consistency, the subjects were asked to choose one ear to use throughout the entire testing process. Three of the subjects (the male subjects) chose to use their right ear, while the other (the female subject) preferred the left ear.

The participants were required to come to the lab two hours per day for up to five days per week. To compensate for their time, those who volunteered to participate were reimbursed at a rate of seven dollars per hour (3 out of the 4 subjects were paid). The investigator served as subject #1 in the experiment. The data collection took two full weeks. Each subject listened to the signals for nine to ten hours on average. This is equivalent to 10,000 to 15,000 trials of the experiment. The subjects practiced the task until consistency in the results was observed for each individual. Then, each subject was ready to begin the procedure used in data collection.

Stimuli:

This study of direction identification used a two-interval, forced-choice procedure in order to investigate the possible role of response bias in the results. Only linear frequency-modulated (FM) glides were used in the present experiment. The "signal" interval was an upward or downward frequency sweep. The signals were produced across three center frequencies, 850, 2250 and 3850 Hz, and with duration of 15 ms for the high and middle frequency ranges, and 20 ms for low frequency range. For the low frequency range the duration was 20 ms, because a longer period results in fewer cycles being encoded by the auditory system. To prevent onset and termination "clicks," a 5 ms rise/decay was used. This meant that a 15 ms glide would rise during the first 5 ms of the glide, maintain the same intensity for 15 ms in the middle of the glide, and fall in intensity for the final 5 ms. The frequency span of the glide was 0.35 ERB (equivalent rectangular bandwidth) centered around each center frequency (Hartmann, 1997). The non-signal interval contained pure tones that maintained a constant frequency over the entire duration, which was equal in duration to the interval containing the signal.

The subjects were tested in a laboratory with three separate single-walled sound attenuating rooms. The main room contained a laboratory PC used to send commands to a smaller notebook inside the sound booth. Matlab 5.3 was used to conduct all psychoacoustical experiments. A Tucker/Davis System II was used to generate the stimuli. The subjects listened to the tones through Sennheiser HD 580 supra-aural headphones, always directed to the same ear at comfortable supra-threshold levels for the listeners.

Procedures:

The subjects listened to four blocks of 50 trials at each center frequency: 850, 2250 and 3850 Hz. Therefore, a total of 200 trials were used in determining the average for each subject at each center frequency. During each trial in the block of 50 trials, the subjects listened to two intervals. Then, they chose which interval contained the glide that changed in frequency, as opposed to the pure tone. The duration, center frequency, and ERB separation was held constant over each set of 50 trials, but the direction of the glide and the interval containing the glide varied.

The two-interval forced choice procedure used in this study controls listener behavior to minimize response bias. The subjects pushed the left button if they thought the first interval contained the signal and the right button if the second interval contained the signal. The subjects were allowed to hear each interval only once, and must then choose their response. In addition, the subjects were given visual feedback following each choice to reveal which interval actually contained the signal. The feedback aided each subject during the practice sessions.

As the duration of the tone and ERB separation decreases, the task becomes more difficult for the listener. Fifty percent accuracy is “chance” performance. Even when guessing between two possible intervals, the lowest percent of correct responses should be fifty percent. In addition, when the task becomes too easy, subjects achieve 100 percent accuracy on almost every block. In this case, there is no possible way to see a clear cut difference in the performance of the subjects in determining “up” vs. “down” glides. Therefore, optimal parameters were sought to produce results close to seventy-five percent accuracy by adjusting frequency, duration and ERB separation.

Also, roving was used to make the task more difficult for the listeners. By roving the frequencies, both the glide and the pure tone could have started at any point in the frequency span being used. The glide then moved either up or down in frequency. As a result, the listeners were required to attend to the full duration of both tones before determining which interval contained a glide. This made the task more difficult, because the subjects were required to listen to the entire duration of each interval, rather than just the beginning or ending of a particular interval.

Figure 3.1 demonstrates the screen the subjects used to choose their responses following each trial. Before each block, a red “warning” light is illuminated to notify the subject the experiment is ready to begin. The subject then clicks on either mouse button to begin. Two intervals are then presented. During the first interval, the light signifying the first interval is being played flashes, and likewise the second light glows for the second interval. At this point, the subject must choose which interval contained the signal, and the “awaiting answer” light appears at the top middle of the screen. The subject must then click the left mouse button if they thought the first interval contained the signal and the right button if the second interval contained the signal. Once an answer is submitted the light on the top right-hand side quickly flashes indicating that the answer was received; quickly following this, one of the two “interval” lights re-appears to reveal the correct answer to the subject. This gives the subject feedback to every response.

The experiment was randomized in two different ways. First, the signal (glide) was randomized between the first and second interval. Therefore, half of the first intervals contained the signal, while the remaining half of the time the second interval contained the signal. The direction of the glide was also randomized. On average, the glide rose in frequency in half of the trials and fell in the remaining half. As a result, there were four possible ways the tones could be presented: the glide occurring in the first interval and rising in frequency, the glide occurring in the second interval and rising in frequency, the glide occurring in the first interval and falling in frequency, or the glide occurring in the second interval and falling in frequency.

The computer calculated a percentage of correct responses for two instances: when the signal was rising in frequency and when the signal was falling in frequency. On average, half of the trials (about 25) contained a signal rising in frequency, and the remaining fell in frequency. Upon completion of each block of trials, the two percentages were recorded. The percent correct for up responses and the percent correct for down responses was then averaged over the four blocks of trials at the same duration and frequency span for each listener. These averages were then used to formulate various psychometric functions in order to analyze the results.

The number of times each listener answered by clicking the left and right mouse buttons (indicating the first or second interval contained the signal) was also tallied. Through one block of 50 trials, it is expected that the subject will choose interval one half of the time and interval two the other half of the time. If a subject chooses interval one 40 times and interval two only 10 times, there is blatant evidence that suggests bias could have affected the results of their portion of the experiment. In order to detect if bias exists throughout any or all of the testing process, the number of times each interval was chosen was recorded and averaged.

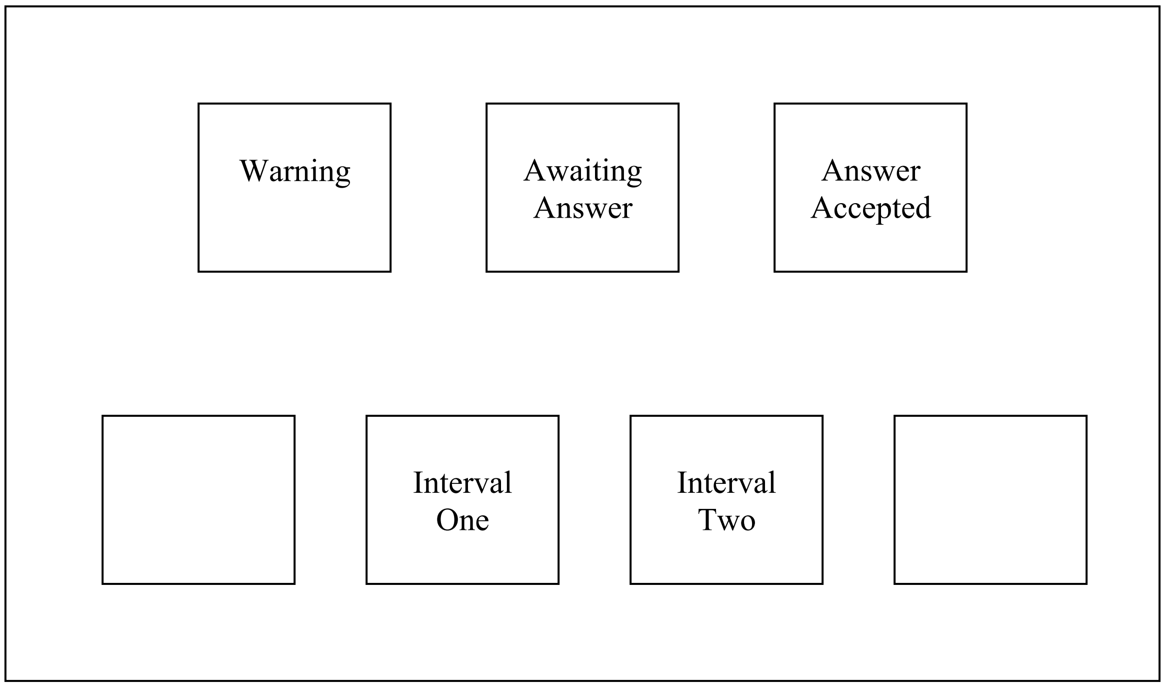

Figure 3.1 – A representation of the screen display and various lights seen by subjects who performed in the experiment.

Chapter Four – Results

Following several hours of practice, a plateau in each subject's performance was identified at each center frequency (F_c): 850, 2250 and 3850 Hz. After this consistent pattern in their performance was evident, the subjects listened to four blocks of 50 trials for each frequency range. The findings from these 12 blocks constitute the final data used in analyzing the experiment. The set of four blocks was averaged for each subject at each center frequency. The four subjects' results were then compared and averaged together for a grand average at each center frequency. Figures 4.1, 4.2 and 4.3 represent the subject averages and the grand average for each center frequency.

The three primary questions raised in the present study include:

1) Do the results of the study demonstrate a similar pattern in direction identification observed by the both the Dawson and Feth (2002), and Gordon and Poeppel (2001) studies?

2) Does the difference in performance between "up" vs. "down" glides vary with center frequency?

3) Do any of the subjects exhibit a response bias?

Although the four subjects were all normal-hearing undergraduates, small individual differences were noted. For example, some of the subjects required more practice in order to master the task. Others showed little, if any, need for practice. Those with a musical background (subject #1 and #2) needed the least practice to master this task. In addition, the difference in performance between responses for intervals containing a rising glide and a falling glide varied for all subjects at each center frequency (see Table 4.1 for a breakdown of the results). The number of times each subject answered the first or second interval were tallied and analyzed for the possibility of response bias affecting the resulting data of the experiment. In this two-interval setting, the proportion of responses for the first and second intervals should equal 0.5. For example, if a subject answered the first interval on 25 of the trials and the second interval on the remaining 25, $p = 0.5$. To show no evidence of response bias, the proportion should approximate 0.5 for every subject. Likewise, there are small differences existing in these figures for each individual. However, small differences in performance, though noticed, are expected.

Subject #1, the investigator, had the most practice prior to performing the set of trials used in the final data. Although consistent results were being produced early on, the subject engaged in hours of extra practice searching for the experimental parameters. By examining the three charts (Figures 4.1, 4.2 and 4.3) one can see that subject #1 typically performed the best over the three frequency ranges. Additionally, subject #1 outperformed the others substantially in identifying “down” intervals (12.5% higher than group average at 3850 and 850 Hz, and 9.3% higher at 2250 Hz). Furthermore, the difference in performance between “up” and “down” was the least significant. This all could be a direct result of subject #1 practicing the task the most. However, this individual does have a minor history in music and could be better trained to recognize small pitch differences that occur between two intervals.

Subject #2 required the least practice before demonstrating asymptotic performance across all frequencies used in the experiment. Subject #2 is very active in music and plays the guitar regularly. Therefore, it is evident that a musical background yields higher performance in this type of direction identification task. Furthermore, those experienced in music are better trained to hear small differences in pitch, akin to the small pitch difference heard in a linear FM glide used in this study. Although subject #2's performance gap in "up" vs. "down" at 3850 and 2250 Hz is smaller than the average across the group, the gap observed at 850 Hz is the largest (Figure 4.1).

Subject #3 was the only participant who chose to use the left ear for testing. For this listener, an average amount (nine to ten hours) of practice was needed to master the task. With just a glance at the middle frequency bar graph (Figure 4.2), one will notice the sizeable difference in performance in the direction identification task for subject #3. This disparity of 97% correct for "up" to 66.6% for "down" is the most remarkable difference observed at any center frequency for any subject. Also noteworthy, despite performing so well when the signal was "up" at 2250 Hz, subject #3 performed the poorest for glides at 3850 Hz (Figure 4.3). This is very uncharacteristic, as previous research indicates that high frequencies typically yield the higher performance in a direction identification task (Gordon and Poeppel, 2001).

Subject #4 required the most practice. In fact, subject #4 practiced for almost twice the number of hours (approx. 12 hours) of subject #2 before asymptotic performance was achieved. In addition, this individual has experienced no musical training. Accordingly, the average performance in the direction identification task over all three center frequencies was the lowest for subject #4. Still, the gap in intervals containing "up" vs. those containing "down" was consistent with the group averages.

Upon further inspection of the group averages, a variety of differences occurring between the 850, 2250 and 3850 Hz center frequencies are evident (Table 4.1). For example, for intervals containing a glide falling in frequency, the group tended to perform better as the frequency increased. However, the same relationship of frequency and performance was not as obvious for intervals containing the "up" signal. Most subjects performed their best in detecting glides rising in frequency at 2250 Hz. However, the performance at 3850 Hz was also superb, followed by glides occurring at the 850 Hz center frequency. Finally, the largest disparity in identifying the direction of tone glides is found when F_c equals 2250 Hz.

The t-test is used to assess whether the means of two groups are statistically different from each other, such as responding to this task with the first or second interval. Furthermore, it will judge two means relative to the spread or variability of their scores. An arc-sign transform was performed on the subject accuracy percentages for "up" and "down" responses. A t-test was then assessed to these results. In most research, the alpha level is set at 0.05 (in one of twenty cases, you would find a statistically difference between the means if there was none). For this experiment, only when $F_c = 3850$ Hz did the results pass the t-test at the $\alpha = 0.05$ level.

Statistical analysis was carried out using the binomial test (Gravetter & Wallnau, 2000). For $p = q = 0.5$ (p and q being the first and second interval) and $n = 600$, an approximation to a z-score is calculated from: $z = [(x / n) – p] / \sqrt{[(pq) / n]}$, where (x / n) is the proportion of "up" responses over 600 trials. For unbiased responding, $p = q = 0.5$ ("up" and "down" responses are equally-likely). For significance at the 0.05 level, $z \geq 1.96$. Thus, if the calculated z-score exceeded 1.96, the listener responses were biased. For $z < 1.96$, the test supports an unbiased response. After performing the binomial test on all four subjects, only subject #4 exhibited a response bias.

Experimental Data

	850 Hz. % Up	850 Hz. % Dn	Difference
Subject No. 1	82.8%	80.0%	2.8%
Subject No. 2	82.0%	63.7%	18.3%
Subject No. 3	76.5%	63.8%	12.7%
Subject No. 4	70.2%	62.3%	7.9%
Average	77.9%	67.5%	10.4%

	2250 Hz % Up	2250 Hz % Dn	Difference
Subject No. 1	94.3%	84.5%	9.8%
Subject No. 2	81.0%	78.6%	2.4%
Subject No. 3	97.0%	66.6%	30.4%
Subject No. 4	83.6%	71.2%	12.4%
Average	89.0%	75.2%	13.8%

	3850 Hz % Up	3850 Hz % Dn	Difference
Subject No. 1	98.3%	93.0%	5.3%
Subject No. 2	91.5%	84.6%	6.9%
Subject No. 3	77.9%	68.3%	9.6%
Subject No. 4	83.0%	76.0%	7.0%
Average	87.7%	80.5%	7.2%

Table 4.1 – Percentage of correct responses in a two-interval, forced-choice task. Column #1 shows results for rising glides; column #2 displays results for falling glides. The third column is the difference: $P(c)_{up} - P(c)_{dn}$.

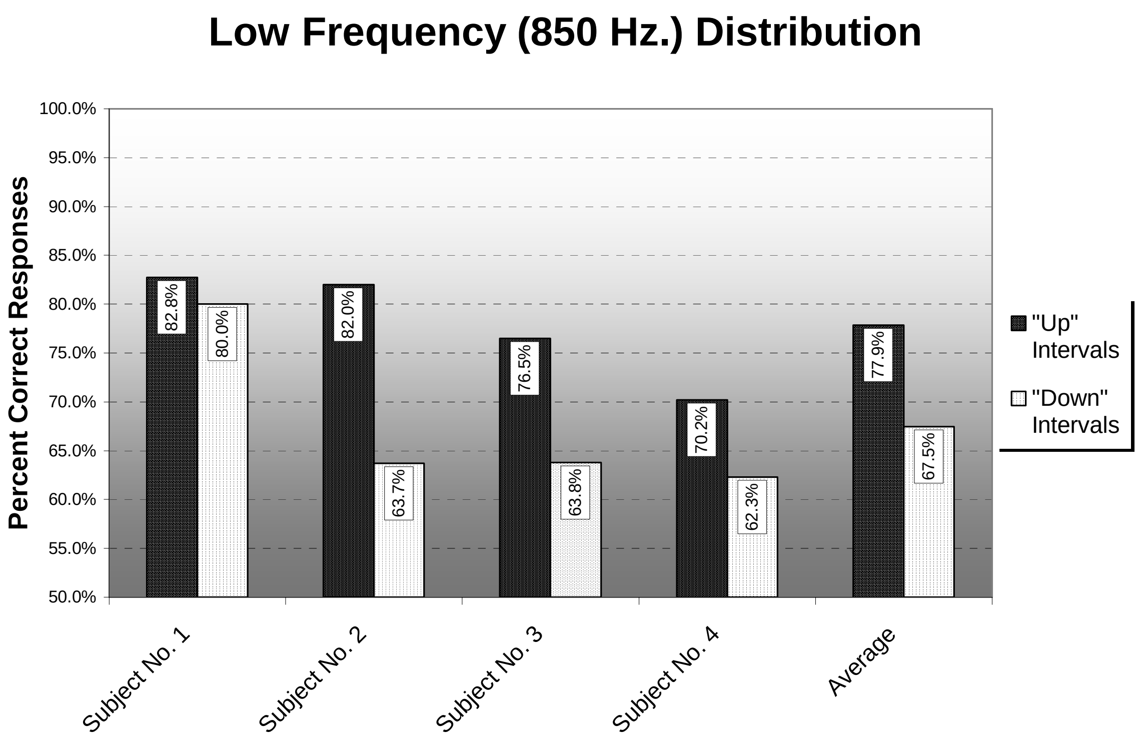

Figure 4.1 – Percentage of correct responses in a two-interval, forced-choice task for detection of a glide tone versus a steady tone. Performance is separated for rising glides (up) and falling glides (down). F_c = 850 Hz

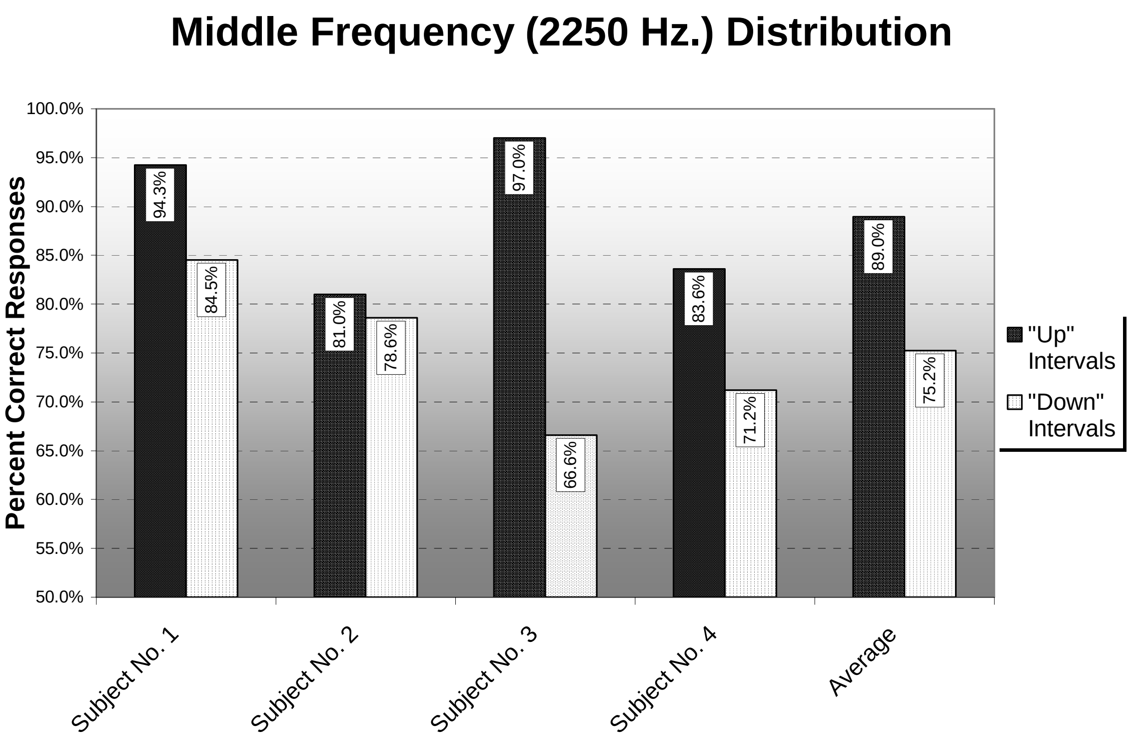

Figure 4.2 – Percentage of correct responses in a two-interval, forced-choice task for detection of a glide tone versus a steady tone. Performance is separated for rising glides (up) and falling glides (down). F_c=2250 Hz

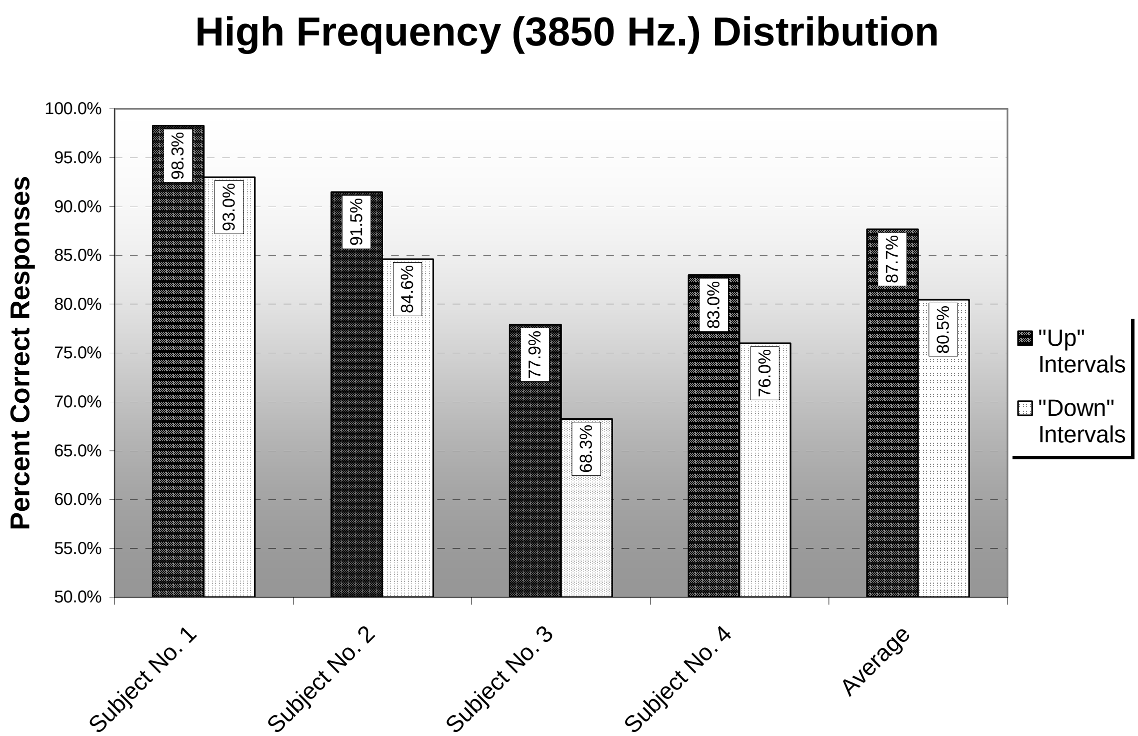

Figure 4.3 – Percentage of correct responses in a two-interval, forced-choice task for detection of a glide tone versus a steady tone. Performance is separated for rising glides (up) and falling glides (down). F_c=3850 Hz

Chapter Five – Discussion

Earlier studies by Gordon and Poeppel (2001) and Dawson and Feth (2002) reported that human listeners can identify glides rising in frequency with higher accuracy than those falling in frequency. In addition, they determined that performance increases as frequency and duration increase. Dawson and Feth's study focused on replicating the results of the Gordon and Poeppel study for virtual-frequency (VF) glides as well as FM glides. They argued that VF glides and FM glides are processed centrally in the same way, so a similar pattern in direction identification found by Gordon and Poeppel for FM glides should also be evident for VF glides.

Originally, Dawson and Feth (2002) had difficulty producing the same results as the Gordon and Poeppel (2001) study. The task proved to be very easy for listeners with a little practice. Roving of the glide frequencies had to be introduced before the expected pattern in direction identification was observed. By roving the frequencies, listeners had to listen to the full duration of each glide. Glides could now start anywhere within a fixed range around a particular center frequency and move upward or downward in frequency. However, the difference in listener performance in identifying the direction of glides was still not as substantial as previous research suggested, even after the introduction of roving to the task. Finally, Dawson and Feth noted that performance was better on FM glides vs. VF glides due to the FM glide being more salient.

Did the results of the present study agree with those found by Gordon and Poeppel (2001) and Dawson and Feth (2002)? The data collected in this study did in fact support previous work in direction identification. Primarily, as the center frequency increased, listener performance in identifying upward and downward frequency sweeps increased. Subjects could best detect a falling glide at 3850 Hz. This is also the only center frequency that passed the t-test at the $\alpha = 0.5$ level. Still, the subjects were slightly better at identifying a rising glide at 2250 Hz (89.0%) than at 3850 Hz (87.7%). The t-test is used to measure if the difference between "up" and "down" glides are significant over the entire group. VF glides were not used in this experiment. It was assumed that if the results in this two-interval experiment for FM glides supported the results from the Dawson and Feth study, and if VF glides and FM glides are processed in the same way in the brain, that VF glides would show the same pattern demonstrated by FM glides in the present experiment. The purpose of this study was to reveal if a response bias existed.

Does the difference in performance of "up" vs. "down" glides vary with center frequency? For the most part, the asymmetry in performance between intervals containing a rising glide and a falling glide increased as center frequency increased. In addition, the smallest difference between listener performance in upward and downward frequency sweeps occurred at the highest center frequency, $F_c = 3850$ Hz (the average difference in performance between "up" and "down" glides was 7.2%). Here, the overall accuracy was also the best, with most subjects identifying between 68% and 98% of glides correctly. One could argue that when given 15 ms at both 3850 Hz and 2250 Hz, more cycles of the signal are processed by the brain at the higher center frequency. However, upward glides were detected at nearly the same percentage for both center frequencies.

The largest gap in direction identification performance between glides rising and falling in frequency occurred at 2250 Hz. Although subjects identified downward sweeps with better accuracy at 3850 Hz, they detected upward glides slightly better at 2250 Hz;

therefore, a larger gap in performance in “up” vs. “down” exists (difference of 13.8%). Subjects performed the poorest at the lowest center frequency, F_c = 850 Hz. On average, listeners were able to identify glides between 62% and 82% of the time at 850 Hz. Therefore, not only do results vary between subjects, but also between center frequencies.

Response bias could be an alternative explanation for the results found by both of the previous studies on direction identification. The issue of bias serves as the hypothesis of the current study. When the situation exists that it became difficult for a listener to discriminate between a rising and falling glide, it is possible that the listener had a fixed preference for always answering “up” or “down.” With the single-interval experiment used in previous research, there is no way to measure the possible existence of bias. However, the present study used a two-interval experiment which allows for the identification of bias.

Previous research on direction identification involved studies based on single-interval procedures. Gescheider (1976) calls this type of task a *yes-no procedure* and explains that different criterion levels can be obtained by adjusting signal probability or payoff contingencies. Although subjects should answer both “up” and “down” each on about half of the trials, it is more difficult to control response bias in this setting. The present study was based on a two-interval, or *forced-choice procedure*. Instead of determining if a single glide was moving upward or downward in frequency, subjects were asked to simply identify which of the two intervals contained a glide. Therefore any fixed preference to choose “up” or “down” (or in this study, “1^{st}” or “2^{nd}” interval) could not exist. In addition, bias could now be measured. Since the experiment was two-way randomized (in glide direction and between which interval contained the signal), subjects should have responded by choosing the first and second interval each about half of the time. Statistics could now be recorded to identify how many times each interval was chosen in order to recognize response bias.

Do any of the subjects exhibit a response bias? After performing the binomial test (Gravetter and Wallnau, 2000) on for each subject over 600 trials, only subject #4 exhibited a response bias. Subject #4 also required the most practice before asymptotic performance was observed. Subject #1 was the most unbiased of the group. This could be due to this subject being the investigator, who had much more practice than the others. Overall, the results approximated the probability of 0.5 for the first or second interval containing the signal, with only one biased subject in four. See Figure-B in the appendix for subject responses and their respective averages.

A two-interval, forced-choice experiment is one way to investigate the possibility of response bias in direction identification tasks. However, there are other ways to ensure unbiased testing. Most notably, Kaernbach (1990) explains the format for an unbiased single-interval procedure. By adjusting the level (intensity) of the signal in a staircase manner, it is possible to obtain unbiased results. This type of experiment is called a single-interval adjustment-matrix (SIAM) procedure. The intensity of the signal continues to decrease as the listener correctly responds to each glide. When a response is incorrect, the level begins to rise again using this staircase technique. Once a set number of reversals in the level has been achieved, testing ends for that sequence. This method has been proven as the fastest of all unbiased procedures. Not only do subjects listen to only one interval per block, but the number of trials decreases immensely for each time block.

One might suggest using more center frequencies in the present setup. With time constraints, it was logical to use three center frequencies: 850, 2250, and 3850 Hz. Previous studies used multiple durations for each center frequency. However, when using a two-interval procedure, the task proved to be very easy unless the duration was less than 25 ms. Therefore, a testing format that uses more durations would be possible under a single-interval adjustment-matrix setup. In conclusion, the present study proved the validity of the previous studies by further investigation of response bias. The results of this study support earlier findings in direction identification of tone glides, with three of the four subjects showing no evidence of response bias.

The results of this study support the conclusion that asymmetry between the accuracy of correct responses for intervals containing “up” vs. “down” glides is not due to just response bias. Dawson and Feth (2002) reported that a similar pattern in direction identification found using FM glides was also observed for virtual-frequency glides. Although FM and VF glides are processed in the same way centrally, their activity on the basilar membrane is very different. Therefore, the asymmetry has no peripheral explanation. In order to replicate the Dawson and Feth (2002) study of the comparison of FM and VF tone glides by controlling response bias, the SIAM procedure should be implemented.

Since response bias did not play a role in the tone glide direction study, there must be an alternate explanation. The traveling wave of the basilar membrane always moves from base to apex. Therefore, it travels from high frequencies to low frequencies. A tone glide moving upward in frequency moves against the traveling wave, but a glide moving downward in frequency moves with the traveling wave. Still, VF glides do not move with or against the traveling wave, since the energy does not move from one frequency to another. Future research should focus on brain activity of the central auditory system.

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Appendix

850 Hz	UP	DOWN		ASIN(UP)	ASIN(DN)			
S1	0.828	0.800		0.976	0.927		T value	-0.379
S2	0.082	0.637		0.082	0.691		P value	0.730
S3	0.765	0.638		0.871	0.692		Degrees of Freedom	3.000
S4	0.702	0.623	0.650	0.778	0.673	0.730		
3350 Hz								
S1	0.943	0.845		1.232	1.007		T value	2.246
S2	0.810	0.786		0.944	0.904		P value	0.110
S3	0.970	0.666		1.325	0.729		Degrees of Freedom	3.000
S4	0.836	0.712	0.104	0.990	0.792	0.110		
3850 Hz								
S1	0.983	0.930		1.386	1.194		T value	9.432
S2	0.915	0.846		1.156	1.008		P value	0.003
S3	0.779	0.683		0.893	0.752		Degrees of Freedom	3.000
S4	0.830	0.760	0.004	0.979	0.863	0.003		

Figure A – Statistical results using the percentages from each subject at each center frequency. Arc-sign transform was performed, followed by a t-test.

Figure B (continued on next page) – Subject responses (1 denotes left button was pushed, 2 denotes right button was pushed) at each center frequency. In the first column, the number indicates the subject and the letter indicates the center frequency (A-850 Hz, B-2250 Hz, C-3850 Hz).

1B	1	1	2	2	2	1	2	1	2	2	1	2	2	1	1	2	1	1	1	1	1	2	2	1	1	2	2	1	1	2	1	2	1	1	1	1	2	2	1	1	2	2	1	1	1	1	2	2	2	1	**0.44**	
1B	1	2	2	1	2	1	2	2	2	2	1	2	1	2	2	2	1	2	1	1	1	1	2	1	2	1	2	1	2	1	2	2	2	1	2	1	2	1	1	2	1	2	1	2	2	2	1	2	1	1	**0.54**	
1B	1	1	2	2	1	2	2	1	1	2	1	1	1	1	1	2	1	2	2	2	1	2	1	2	2	1	2	1	1	2	2	2	2	2	2	2	1	1	2	1	1	2	1	2	2	1	2	1	2	1	**0.52**	
1B	2	2	1	1	1	1	2	1	1	1	2	1	2	2	2	2	2	2	1	2	2	1	2	1	1	2	1	1	1	1	2	1	1	2	2	2	1	1	1	2	1	1	2	2	1	2	1	1	2	1	**0.46**	**0.49**
1C	1	2	2	2	1	2	1	2	2	2	1	1	2	1	1	1	2	1	1	2	1	1	2	2	2	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2	1	1	2	2	1	1	2	2	1	**0.38**	
1C	2	2	2	1	1	1	2	2	2	2	1	2	1	2	1	1	1	2	2	2	2	1	2	2	1	2	2	2	1	2	1	1	2	2	2	2	2	1	1	2	2	1	1	1	1	1	2	1	1	2	**0.56**	
1C	1	1	2	1	1	1	1	1	1	2	2	1	1	2	1	2	2	1	2	2	1	1	2	2	1	2	2	2	2	2	1	1	1	1	1	2	2	2	2	1	2	2	1	2	2	2	2	2	2	1	**0.54**	
1C	2	2	2	1	1	2	2	2	2	1	2	1	1	1	1	2	1	2	1	1	1	1	2	2	2	2	2	1	2	1	2	2	2	1	1	2	1	1	2	1	2	1	1	2	1	2	2	2	1	1	**0.52**	**0.49**
1A	1	1	2	1	2	2	1	2	2	2	1	2	1	2	2	2	2	2	2	1	2	1	1	2	2	2	2	2	2	2	1	2	1	2	2	1	1	1	2	2	1	2	1	2	1	1	1	2	1	1	**0.58**	
1A	1	2	2	2	2	1	2	2	1	2	1	2	1	1	1	1	1	1	2	1	1	2	1	1	1	2	1	2	2	2	2	2	1	2	1	2	1	1	2	1	2	2	2	2	2	2	2	1	1	2	**0.54**	
1A	1	2	1	2	1	2	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1	2	1	1	1	2	2	2	2	2	2	1	1	1	1	2	1	2	1	1	2	2	1	2	1	**0.36**	
1A	1	1	1	1	1	2	2	1	2	1	2	1	1	2	2	1	1	1	1	2	2	1	2	1	2	1	2	2	2	2	1	1	1	1	2	1	2	1	2	2	1	1	2	1	2	2	2	1	2	2	**0.48**	**0.49**
2B	2	2	1	2	2	2	1	2	1	2	2	2	1	1	1	2	1	2	2	2	2	2	1	2	1	1	1	1	2	1	2	2	1	2	1	2	1	2	1	2	2	1	1	2	2	1	1	1	2	1	**0.54**	
2B	2	2	2	1	1	2	2	2	2	2	2	1	2	2	2	2	1	1	1	2	2	2	1	1	2	2	2	2	2	1	2	2	1	2	2	1	1	1	2	1	1	2	1	2	1	2	2	1	1	1	**0.6**	
2B	2	2	1	2	1	1	2	2	2	2	1	2	1	1	2	2	2	1	2	1	2	2	2	2	1	2	2	1	2	2	1	1	2	1	2	1	1	2	2	2	1	2	2	1	2	1	1	2	2	1	**0.6**	
2B	2	1	1	2	2	2	2	1	2	2	2	2	2	2	2	1	1	2	2	1	2	2	2	1	1	1	2	1	2	1	1	2	1	1	2	1	1	1	2	2	1	2	2	2	2	1	2	1	1	1	**0.56**	**0.58**
2C	1	1	2	2	1	2	2	2	2	1	2	1	2	2	2	1	1	1	1	2	1	1	1	1	2	1	2	1	2	2	2	2	1	2	1	2	2	2	2	2	1	1	1	2	1	2	2	2	1	2	**0.56**	
2C	2	2	1	1	1	2	1	1	1	2	1	2	1	2	1	1	2	2	1	1	2	2	2	1	2	1	2	2	1	1	1	1	1	2	1	2	1	1	1	1	1	1	1	1	2	1	1	2	1	1	**0.36**	
2C	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	2	1	2	1	2	2	1	1	2	2	1	2	2	1	2	1	1	2	2	1	2	1	2	2	2	1	2	1	2	2	1	1	2	2	1	**0.52**	
2C	1	2	1	2	2	1	2	2	1	2	2	1	2	2	1	1	1	2	2	2	1	2	1	1	2	1	1	1	2	1	2	1	1	2	1	2	1	1	2	2	1	2	2	1	1	2	1	1	2	2	**0.5**	**0.49**
2A	1	2	1	2	1	1	2	1	1	2	2	1	1	1	2	1	1	1	2	1	1	2	1	1	2	1	2	1	2	1	2	2	1	2	1	2	1	2	1	2	1	2	1	1	1	2	2	2	2	1	**0.44**	
2A	2	2	1	1	2	2	2	2	1	1	1	1	1	2	1	1	1	2	2	1	1	2	1	1	2	2	1	1	1	1	2	1	2	1	2	2	1	1	1	1	1	1	1	1	2	2	1	2	1	2	**0.4**	
2A	2	1	1	2	2	1	2	1	2	1	1	2	1	1	1	2	2	1	1	2	1	1	2	1	1	2	1	2	1	1	2	1	2	1	1	2	2	1	1	2	1	2	1	2	2	1	1	1	2	2	**0.44**	
2A	2	1	1	1	1	2	1	2	2	1	2	1	1	1	1	2	2	1	1	1	2	2	2	1	2	2	1	1	1	1	1	1	1	1	2	1	1	2	2	1	2	1	1	2	1	2	2	1	1	2	**0.4**	**0.42**

3B	2	2	2	2	2	1	1	1	2	2	2	1	1	2	2	1	1	2	2	1	2	2	1	2	1	2	1	1	2	1	1	2	2	2	1	2	1	2	2	1	2	2	2	2	2	1	1	2	2	1	**0.6**	
3B	2	2	2	1	2	2	1	2	2	2	2	2	1	1	2	1	1	2	1	2	2	1	2	1	2	1	1	2	2	1	2	1	2	2	1	1	1	1	2	1	2	1	1	1	2	2	2	1	1	1	**0.52**	
3B	2	2	2	1	2	1	2	2	1	1	1	2	2	2	1	2	2	1	2	1	2	1	1	2	2	1	2	2	2	2	1	1	1	2	1	2	1	2	2	2	2	1	2	1	1	1	2	2	1	1	**0.56**	
3B	2	1	1	1	2	2	1	1	2	1	1	2	1	1	1	2	1	2	2	2	2	1	2	1	2	2	2	2	2	2	1	2	2	1	2	1	2	1	2	2	2	2	1	1	1	2	2	2	1	2	**0.58**	**0.57**
3C	1	2	2	1	2	2	1	2	2	1	1	2	1	1	2	1	1	2	2	1	1	2	2	2	1	1	1	2	2	2	2	1	1	1	1	2	1	1	2	2	1	1	2	1	1	1	2	1	2	1	**0.46**	
3C	1	1	1	1	2	1	1	2	1	1	1	1	1	1	1	2	1	2	1	2	2	2	2	1	2	1	1	2	1	1	2	2	1	2	1	2	1	1	1	1	1	1	1	2	2	1	2	1	1	2	**0.36**	
3C	2	2	1	1	1	1	2	1	1	1	1	1	2	1	2	1	1	1	1	2	1	1	1	2	1	1	2	1	2	2	1	2	1	2	1	2	1	1	2	2	2	1	2	2	2	1	2	2	2	1	**0.44**	
3C	1	2	1	1	1	2	1	2	2	1	1	2	2	1	2	2	1	2	1	1	1	1	2	2	1	2	1	1	1	2	1	2	1	1	1	1	2	2	1	1	2	1	1	2	2	2	1	2	2	2	**0.46**	**0.43**
3A	1	1	1	2	1	1	2	2	1	1	1	2	1	1	2	1	1	2	2	1	1	2	2	2	1	1	2	1	1	2	2	2	1	2	2	2	2	1	2	2	1	1	2	2	2	2	2	2	1	2	**0.54**	
3A	1	2	2	2	2	1	2	2	1	2	2	1	1	2	2	2	2	1	2	2	1	2	1	2	1	2	2	1	2	2	1	2	2	2	1	1	2	1	2	2	2	1	1	2	1	2	1	2	2	1	**0.62**	
3A	1	1	2	1	2	2	1	1	2	2	1	2	2	2	2	1	1	1	1	1	1	2	2	2	1	2	2	2	2	2	1	1	1	2	1	2	1	1	1	1	2	1	1	1	1	2	2	1	2	1	**0.46**	
3A	2	2	2	1	2	2	2	2	2	1	1	2	1	1	1	1	2	1	1	1	2	2	2	1	2	2	1	2	2	2	2	2	1	2	1	1	2	1	1	2	1	2	2	2	2	2	2	1	1	1	**0.58**	**0.55**
4B	2	1	2	1	2	2	1	2	2	2	2	2	1	1	2	1	2	2	1	2	2	1	2	1	2	2	1	1	1	1	2	2	2	2	1	2	1	2	2	2	2	2	1	2	2	2	2	2	1	2	**0.66**	
4B	2	1	1	1	2	1	2	2	1	1	1	2	2	2	2	1	1	2	1	1	2	1	2	2	1	2	1	2	2	2	1	2	2	2	2	2	2	2	1	2	1	2	1	2	2	2	1	2	2	1	**0.6**	
4B	1	1	2	1	2	2	2	1	2	1	2	2	2	2	1	2	2	2	1	2	1	1	1	2	2	1	2	1	2	2	1	2	2	2	1	1	2	2	2	2	1	1	1	2	2	2	2	1	1	2	**0.6**	
4B	1	1	2	2	1	2	2	2	1	2	2	1	2	2	2	2	2	2	1	2	2	2	2	1	1	2	1	2	2	1	2	1	1	1	1	2	2	2	1	1	2	2	2	2	2	2	2	1	1	1	**0.62**	**0.62**
4A	2	1	2	2	2	2	2	2	1	1	2	2	1	1	2	2	2	1	2	1	1	1	1	1	2	2	1	2	2	2	1	2	2	1	2	2	1	2	1	2	1	1	1	1	2	2	1	2	2	2	**0.58**	
4A	1	2	2	1	1	2	2	2	2	1	2	2	1	2	1	1	2	1	2	1	2	2	1	2	2	1	2	1	1	2	1	2	1	1	2	2	2	2	2	2	2	2	1	1	2	1	1	2	2	1	**0.58**	
4A	2	1	2	2	2	1	2	1	1	1	2	2	1	2	1	1	1	2	2	1	2	2	2	1	2	1	2	1	1	2	2	2	2	2	2	1	1	2	1	2	1	1	2	2	1	1	2	2	2	2	**0.58**	
4A	2	2	2	2	2	2	2	2	2	1	1	2	2	1	1	2	2	1	2	2	2	2	1	1	2	1	2	1	1	2	2	2	1	2	2	1	1	1	2	2	2	2	2	1	2	1	2	2	2	1	**0.66**	**0.60**
4C	1	1	2	1	2	2	2	2	2	2	1	2	1	1	2	1	1	2	1	1	1	1	2	2	1	2	2	2	1	1	2	2	2	1	2	1	1	1	1	1	1	2	1	2	1	2	1	1	2	1	**0.46**	
4C	2	2	2	1	2	1	2	2	1	2	2	1	1	1	1	2	2	2	2	1	1	1	1	2	2	1	2	1	1	1	2	2	2	1	1	1	1	1	2	1	2	1	1	2	1	2	2	2	1	1	**0.48**	
4C	2	2	2	1	2	2	1	1	1	1	2	1	2	1	2	2	2	1	2	1	1	2	2	1	1	1	2	1	2	2	2	2	1	1	1	1	2	1	1	2	2	1	1	1	1	2	2	2	2	1	**0.5**	
4C	2	1	2	2	1	2	2	1	2	1	1	2	2	1	1	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	2	1	2	2	2	1	1	1	1	2	1	2	1	1	1	2	1	**0.36**	**0.49**